

ACT-07/01, CTP-TAMU-24/01  
 CERN-TH/2001-168, UA/NPPS-8-01  
 HEPHY-PUB 741/01  
 hep-ph/0107151

## Dark Matter Direct Searches and the Anomalous Magnetic Moment of Muon

A. B. Lahanas<sup>1</sup>, D. V. Nanopoulos<sup>2</sup> and V. C. Spanos<sup>3</sup>

<sup>1</sup> *University of Athens, Physics Department, Nuclear and Particle Physics Section,  
 GR-15771 Athens, Greece*

<sup>2</sup> *Department of Physics, Texas A & M University, College Station, TX 77843-4242,  
 USA, Astroparticle Physics Group, Houston Advanced Research Center (HARC),  
 Mitchell Campus, Woodlands, TX 77381, USA, and  
 Academy of Athens, Chair of Theoretical Physics, Division of Natural Sciences,  
 28 Panepistimiou Avenue, Athens 10679, Greece*

<sup>3</sup> *Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften,  
 A-1050 Vienna, Austria*

### Abstract

In the framework of the Constrained Minimal Supersymmetric Standard Model (CMSSM) we discuss the impact of the recent experimental information, especially from E821 Brookhaven experiment on  $g_\mu - 2$  along with the light Higgs boson mass bound from LEP, to the Dark Matter direct searches. Imposing these experimental bounds, the maximum value of the spin-independent neutralino-nucleon cross section turns out to be of the order of  $10^{-8}$  pb for large values of  $\tan\beta$  and low  $M_{1/2}, m_0$ . The effect of the recent experimental bounds is to decrease the maximum value of the cross section by about an order of magnitude, demanding the analogous sensitivity from the direct Dark Matter detection experiments.

Supersymmetry, or fermion-boson symmetry, is an omnipotent and ubiquitous element in our efforts to construct a unified theory of all fundamental interactions observed in nature. At very high energies, close to the Planck scale ( $M_P$ ) it is indispensable in constructing consistent string theories, thus dubbed superstrings. At low energies ( $\sim 1$  TeV) it seems unavoidable if the gauge hierarchy problem is to be resolved. Such a resolution provides a measure of the supersymmetry breaking scale  $M_{SUSY} \approx \mathcal{O}(1 \text{ TeV})$ . There is, albeit circumstantial or indirect, evidence for such a low-energy supersymmetry breaking scale, from the unification of the gauge couplings [1] and from the apparent lightness of the Higgs boson as determined from precise electroweak measurements, mainly at LEP [2]. Furthermore, such a low energy SUSY breaking scale is also favored cosmologically. As is well known,  $R$ -parity conserving SUSY models, contain in the sparticle spectrum a stable, neutral particle, identifiable with the lightest neutralino ( $\tilde{\chi}$ ), referred as the LSP [3]. One can then readily show [3] that such a LSP with mass, as low-energy SUSY entails, in the 100 GeV – 1 TeV region, may indeed provide the right form and amount of the highly desirable astrophysically and cosmologically Dark Matter (DM). As times goes by, the experimental evidence for DM, from different quarters, strengthens in such a way, that it has assumed a central role in the modern cosmology. The most recent evidence, coming from the observation of the first three acoustic peaks in the Cosmic Microwave Background (CMB) radiation small angle ( $\theta \lesssim \mathcal{O}(1^\circ)$ ) anisotropies [4], is of tantalizing importance. It is not only provides strong support to a flat ( $k = 0$  or  $\Omega_0 = 1$ ), inflationary Universe, but it also gives an unprecedented determination of  $\Omega_M h_0^2 \approx 0.15 \pm 0.05$ , which taking into account the simultaneously determined baryon density  $\Omega_B h_0^2 \approx 0.02$ , and the rather minute neutrino density suggests

$$\Omega_{DM} h_0^2 = 0.13 \pm 0.05 \quad (1)$$

One then is tempted to combine this recently determined DM density, assuming, as we do here, that it is all due to neutralini (i.e.  $\Omega_{DM} \equiv \Omega_{\tilde{\chi}}$ ), with other presently available constraints from particle physics, in order to find out what is the chances of observing, soon or in the near future, DM directly in the laboratory by elastic neutralino-nucleus scattering, from the energy deposition in the detectors [5]. These particle physics constraints include the lower bound on the mass of the Higgs bosons ( $m_h \geq 113.5$  GeV) provided by LEP [6], the allowed region for  $b \rightarrow s\gamma$ , at 95% CL range ( $2.33 \times 10^{-4} <$

$\mathcal{B}(b \rightarrow s\gamma) < 4.45 \times 10^{-4}$ ) [7], and the recent results from the BNL E821 experiment [8] on the anomalous magnetic moment of the muon ( $\delta\alpha_\mu = 43(16) \times 10^{-10}$ ), assuming, as we do here, that is all due (at the 1 or 2  $\sigma$  level) to low-energy supersymmetry. It should be stressed that the possibility of a rather sizeable positive contribution to  $g_\mu - 2$  from low energy SUSY in the region of large  $\tan\beta$  and  $\mu > 0$  where the  $b \rightarrow s\gamma$  constraint weakens considerably, has been long strongly emphasized [9]. It is amusing to notice, that in our previous analysis of the direct DM searches [10], done *before* the the BNL E821 announcement, we had paid particular interest in the large  $\tan\beta$  region, since it provided the higher possible rates for direct DM detection! Similar results are presented in Ref. [11]. Actually, as we have stressed for some time now [10,12], one way to get the “right” amount of the neutralino mass density ( $\Omega_{\tilde{\chi}} h_0^2$ ), even for relative high values of  $m_0$  and  $M_{1/2}$ , is to move to the large  $\tan\beta$  region, because efficient neutralino annihilation directly through  $A$  and  $H$  poles, occurs. The annihilation cross sections increase with  $\tan\beta$ : couplings  $A\tilde{\chi}\tilde{\chi}$  and  $A\tau\bar{\tau}$ ,  $Ab\bar{b}$  increase, while  $m_A$  decreases, thus one may also expect a rather appreciable increase in the elastic  $\tilde{\chi}$ -nucleon cross section, as is indeed the case. It may turn out, if the BNL E821 result is due to low energy SUSY, that the imposed lower bounds on  $m_0$ ,  $M_{1/2}$  and lower bounds on  $\tan\beta$  [13–16] make the direct neutralino annihilation, through the  $A$ ,  $H$  poles, the major mechanism for getting the right amount of DM [10,12,17], as well as as being consistent with all available constraints [13,16].

Before presenting our results we shall give a brief account on the numerical analysis employed in this paper. This will be useful in comparing our results with those of other authors. In our analysis we use two-loop renormalization group equations (RGE), in the  $\overline{DR}$  scheme, for all masses and couplings involved, defining the unification scale  $M_{GUT}$  as the point at which the gauge couplings  $\hat{\alpha}_1$  and  $\hat{\alpha}_2$  meet. We do not enforce unification of  $\hat{\alpha}_3$  gauge coupling with  $\hat{\alpha}_{1,2}$  at  $M_{GUT}$ . The experimental value of the  $\overline{MS}$  strong coupling constant at  $M_Z$ , which we consider as input, is related to  $\hat{\alpha}_3$  through  $\alpha_s(M_Z) = \hat{\alpha}_3(M_Z)/(1 - \Delta\hat{\alpha}_3)$ .  $\Delta\hat{\alpha}_3$  represent the threshold corrections which affect significantly the value of  $\hat{\alpha}_3$  at  $M_Z$  and hence, through RGE, its value at  $M_{GUT}$ . The latter turns out to be different from  $\hat{\alpha}_{1,2}(M_{GUT})$ , reflecting the fact that gauge coupling unification is impossible to implement in the constrained scenario with universal boundary conditions

for the soft masses. For the determination of the gauge couplings  $\hat{\alpha}_{1,2}$  we use as inputs the electromagnetic coupling constant  $a_0$  the value of the Fermi coupling constant  $G_F$ , and the  $Z$ -boson mass  $M_Z$ . From these we determine the weak mixing angle, through  $\hat{s}^2\hat{c}^2 = \pi\alpha_0/\sqrt{2}M_Z^2G_F(1 - \Delta\hat{r})$ , and the value of the electromagnetic coupling constant at  $M_Z$ . With  $\Delta\hat{r}$  we denote the correction to the muon decay amplitude. In the  $\overline{DR}$  scheme the latter is related to  $a_0$  through  $\hat{\alpha}(M_Z) = a_0/(1 - \Delta\hat{\alpha}_{em})$ , where  $\Delta\hat{\alpha}_{em}$  are the appropriate threshold corrections (see Ref. [18]). The input value of the strong coupling constant is taken within the experimental range  $\alpha_s(M_Z) = 0.1185 \pm 0.002$ .

In running the RGE's, as arbitrary parameters we take as usual the soft SUSY breaking parameters  $m_0, M_{1/2}, A_0$  the value of  $\tan\beta$  and the sign of the Higgsino mixing parameter  $\mu$ . The top and tau physical masses,  $M_t, M_\tau$ , as well as the  $\overline{MS}$  bottom running mass  $m_b(m_b)$  are also inputs. As default values we consider  $M_t = 175$  GeV,  $M_\tau = 1.777$  GeV and  $m_b(m_b) = 4.25$  GeV although we allow for variations within their experimentally allowed region. The determination of the bottom and tau running masses at  $M_Z$  is done by running  $SU_c(3) \times U_{em}(1)$   $\overline{MS}$  RGE's, using three-loop RGE's for the strong coupling constant. We also include two-loop QED corrections, as well as two-loop contributions from the interference of the QCD and QED corrections. The running  $\overline{MS}$  masses at  $M_Z$  are then converted to  $\overline{DR}$  in the usual way. From these we can extract the corresponding Yukawa couplings at  $M_Z$ . We point out that the important QCD as well as the supersymmetric gluino, sbottom and chargino, stop corrections to the bottom mass are duly taken into account. For the determination of the top Yukawa coupling at  $M_t$  we relate its pole and running masses taking into account all dominant radiative corrections. By running the RGE's we can have the value of the top Yukawa coupling at  $M_Z$ .

The determination of the Higgs and Higgsino mixing parameters,  $m_3^2$  and  $\mu$ , is a more subtle issue. These are obtained by solving the minimization conditions with the one-loop corrected effective potential with all particle contributions taken into account. Since large values of  $\tan\beta$  cause large logarithmic corrections, invalidating perturbation expansion, we solve the minimization equations taking as reference scale the average stop scale  $Q_{\bar{t}} \simeq \sqrt{m_{\bar{t}_1}m_{\bar{t}_2}}$ . At this scale the corrections are numerically small and hence perturbatively valid. Thus in each run we determine  $m_3^2(Q_{\bar{t}}), \mu(Q_{\bar{t}})$ . The values of

$m_3^2(M_Z), \mu(M_Z)$ , whenever needed, can be found by solving the RGE's having as initial conditions the values of these quantities at  $Q_{\tilde{t}}$ .

For the calculation of the lightest supersymmetric particle (LSP) relic abundance, we solve the Boltzmann equation numerically using the machinery outlined in Ref. [12]. In this calculation the coannihilation effects, in regions where  $\tau_R$  approaches in mass the LSP, which is a high purity Bino, are properly taken into account.

Before embarking to analyse our numerical findings it would be beneficial to review the physical mechanism through which the scalar, i.e. spin-independent,  $\tilde{\chi}$ -nucleon cross section ( $\sigma_{scalar}$ ) is enhanced, to levels approaching the sensitivity of ongoing experiments. The  $\sigma_{scalar}$  is enhanced in the region of the parameter space where  $\tan\beta$  is large [10]<sup>1</sup>. The dominant contribution to this regime is the Higgs boson exchange. For given inputs  $m_0, M_{1/2}, A_0$  and the sign of  $\mu$ , Higgs masses decrease as  $\tan\beta$  increases. Hence the contribution of Higgs bosons to neutralino-quark elastic cross section becomes more important in the large  $\tan\beta$  regime. Such a decrease in the mass is not sufficient by itself to increase  $\sigma_{scalar}$ . The major role in this increase plays the coupling of the  $CP$ -even heavy Higgs whose coupling to  $d$ -quark is proportional to  $\frac{\cos\alpha}{\cos\beta}$ , which is proportional to  $\tan\beta$ , when the latter becomes large. The coupling of the light  $CP$ -even Higgs, unlike the heavy Higgs case, does not grow with increasing  $\tan\beta$  but stays constant of order unity. Therefore despite the fact that the heavy  $CP$ -even Higgs is heavier than its light  $CP$ -even counterpart, its contribution may be much larger in the large  $\tan\beta$  region, due to its enhanced coupling to  $d$ -quark. In the large  $\tan\beta$  regime the mass of the heavy  $CP$ -even Higgs can be approximated [10] by the relation

$$m_H^2 \approx m_h^2 + m_A^2 - m_Z^2 - \epsilon, \quad (2)$$

where  $\epsilon$  represents the leading stop 1-loop corrections to the  $CP$ -even Higgs masses. From this is obvious that the lowest  $m_H$  values are obtained in the region where  $m_A$  is light and  $m_h$  is close to its lower experimental bound. Moreover it is worth pointing out that in the large  $\tan\beta$  region neutralino relic densities decrease as we have already emphasized due to both the decrease of the pseudoscalar mass, whose exchange in  $\tilde{\chi}\tilde{\chi} \rightarrow b\bar{b}, \tau\bar{\tau}$  processes

---

<sup>1</sup>Enhancement of  $\sigma_{scalar}$  is also possible in the context of the so-called focus point supersymmetry scenario [19], where  $m_0 > 1.5$  TeV, yet such large values of  $m_0$  are not favourable by the recent  $g_\mu - 2$  data.

is less suppressive, and the increase of the  $\tilde{\chi}\tilde{\chi}A$  as well as the  $A\bar{b}b$  and  $A\tau\bar{\tau}$  couplings. The smallness of the LSP's Higgsino component is compensated by the largeness of  $\tan\beta$  yielding neutralino annihilation cross sections compatible with the recent astrophysical data. Hence there are regions in which we can obtain both low relic densities and high  $\sigma_{scalar}$ .

Bearing all these in mind, we proceed discussing our findings. For our numerical analysis a large random sample of 45,000 points in the region of the parameter space designed by  $2 < \tan\beta < 55$ ,  $M_{1/2} < 1.5$  TeV,  $m_0 < 1.5$  TeV,  $|A_0| < 1$  TeV, and  $\mu > 0$  is used. The  $\mu < 0$  case is not favored by the recent  $b \rightarrow s\gamma$  data, as well as by the observed discrepancy of the  $g_\mu - 2$ , if the latter is attributed to supersymmetry, and therefore we shall not discuss it in the sequel. It is also worth noticing that in the  $\mu > 0$  case the constraint from  $b \rightarrow s\gamma$  data is superseded by the  $m_h > 113.5$  GeV bound, in the bulk of the parameter space [13]. In figure 1 we plot the scalar  $\tilde{\chi}$ -nucleon cross section as function of the LSP mass,  $m_{\tilde{\chi}}$ . On the top of the figure the shaded region (in cyan colour) is excluded by the CDMS experiment [20]. The DAMA sensitivity region (coloured in yellow) is also plotted [21]. Pluses (+) (in blue colour) represent points which are both compatible with the E821 data  $\alpha_\mu^{\text{SUSY}} = (43.0 \pm 16.0) \times 10^{-10}$  and the cosmological bounds for the neutralino relic density  $\Omega_{\tilde{\chi}} h_0^2 = 0.13 \pm 0.05$ . Diamonds ( $\diamond$ ) (in green colour) are points which are cosmologically acceptable with respect to the aforesaid bounds, but the bound to the  $\alpha_\mu^{\text{SUSY}}$  has been relaxed to its  $2\sigma$  region, namely  $11 < \alpha_\mu^{\text{SUSY}} \times 10^{10} < 75$ . The crosses ( $\times$ ) (in red colour) represent the rest of the points of our random sample. Here the Higgs boson mass bound,  $m_h > 113.5$  GeV has been properly taken into account. From this figure it is seen that the the points which are compatible both the  $g_\mu - 2$  E821 and the cosmological data (crosses) yield cross sections of the order of  $10^{-8} - 10^{-9}$  pb and the maximum value of the  $m_{\tilde{\chi}}$  is about 200 GeV. If one considers the  $2\sigma$  region of the  $g_\mu - 2$  bound the preferred cross sections can be as small as  $10^{-10}$  pb and correspondingly the upper bound of  $m_{\tilde{\chi}}$  is drifted up to 350 GeV. In the following figures 2 and 3 the  $\sigma_{scalar}$  is plotted as function of the parameters  $m_0$  and  $\tan\beta$  respectively. One can see that the points which conform to cosmological and  $1\sigma$   $g_\mu - 2$  experimental constraints, yield a maximum value of  $m_0$  about 600 GeV, and for the  $2\sigma$  case 1200 GeV. The aforementioned bounds on the  $m_{\tilde{\chi}}$  and  $m_0$  are related

with the analogous bounds put on the soft parameter  $M_{1/2}$  and  $m_0$  from the  $g_\mu - 2$  E821 data [13, 14, 16].

From figure 3 it is apparent that the majority of the points that are compatible with cosmological and  $g_\mu - 2$  data are accumulated toward rather large values of  $\tan \beta$ , specifically  $\tan \beta > 40$ , although there are indeed few of them with smaller values of  $\tan \beta$ . As it has been already pointed out in the large  $\tan \beta$  region we can have simultaneously cosmologically acceptable values of  $\Omega_{\tilde{\chi}} h_0^2$  and also big values for the elastic cross section  $\tilde{\chi}$ -nucleon. Furthermore the  $g_\mu - 2$  muon data prefer large values of  $\tan \beta$ , as  $\alpha_\mu^{\text{SUSY}}$  is proportional to  $\tan \beta$  [9]. Therefore as  $\tan \beta$  increases large regions of the parameter space  $(m_0, M_{1/2})$  are compatible with the E821 experimental constraints. Taking all these into account it is not surprising that the conjunction of the cosmological and  $g_\mu - 2$  data happens for large values of the  $\tan \beta$  and for large scalar cross section  $\tilde{\chi}$ -nucleon, as it can be perceived from figure 3.

Comparing figure 1 and 4 one can realise how  $g_\mu - 2$  data constrain  $m_{\tilde{\chi}}$  mass to be up to 200 GeV or 350 GeV for the  $1\sigma$  or  $2\sigma$  case respectively. In figure 4 we don't impose the constraints stemming from  $g_\mu - 2$  data, therefore due to the coannihilation processes the cosmologically acceptable LSP mass can be heavier than 500 GeV. What is also important to be noticed about the direct searches of DM is that imposing the  $g_\mu - 2$  data the lowest allowed  $\tilde{\chi}$ -nucleon cross section increased by about 2 orders of magnitude, from  $10^{-11}$  pb to  $10^{-9}$  pb. This fact is very encouraging for the future DM direct detection experiments. Figure 5 illustrates the significance of the Higgs boson mass bound. If one allows for values  $m_h > 100$  GeV many points which yielding cross sections even  $\mathcal{O}(10^{-7})$  pb appear. Comparing figure 1 and 5 we observe that the recent Higgs mass bound ( $m_h > 113.5$  GeV) reduces the maximum value of the scalar cross section for about one order of magnitude, that is from  $10^{-7}$  pb to  $10^{-8}$  pb. There is direct and indirect dependence of the  $\sigma_{\text{scalar}}$  on  $m_h$ . As  $m_h$  decreases its contribution to the  $\sigma_{\text{scalar}}$ , being proportional to  $1/m_h$ , increases leading to larger  $\sigma_{\text{scalar}}$ . The indirect relation of the  $\sigma_{\text{scalar}}$  to  $m_h$  can be perceived from Eq. 2. Light  $m_h$  results to light  $m_H$  and therefore to large  $\sigma_{\text{scalar}}$  again.

Concluding we have studied the impact of the recent experimental information to the DM direct searches. Especially we have considered the effect of the recently reported

deviation of  $g_\mu - 2$  from its SM value, as well as of the light Higgs boson mass bound from LEP experiments. The imposition of these experimental constraints results to a maximum value for the spin-independent  $\tilde{\chi}$ -nucleon cross section of the order of  $10^{-8}$  pb for  $m_{\tilde{\chi}} \sim 100$  GeV as small as allowed by chargino searches, and for  $\tan\beta > 45$  as large as possible for the Higgs states to be as light as allowed by theoretical constraints and experimental searches. As it can be seen from figures 4 and 5 the effect of these experimental constraints is to decrease the maximum value of  $\sigma_{scalar}$  by almost one order of magnitude, and therefore to make the direct detection of the LSP on the future experiments by some means more difficult.

## Acknowledgements

A.B.L. acknowledges support from HPRN-CT-2000-00148 and HPRN-CT-2000-00149 programmes. He also thanks the University of Athens Research Committee for partially supporting this work. D.V.N. acknowledges support by D.O.E. grant DE-FG03-95-ER-40917 and thanks the CERN Theory Division for hospitality during the completion of this work. V.C.S. acknowledges support by a Marie Curie Fellowship of the EU programme IHP under contract HPMFCT-2000-00675.



## References

- [1] J. Ellis, S. Kelley and D. V. Nanopoulos, Phys. Lett. B260 (1991) 131; U. Amaldi, W. de Boer and H. Furstenau, Phys. Lett. B260 (1991) 447; C. Giunti, C. W. Kim and U. W. Lee, Mod. Phys. Lett. A6 (1991) 1745.
- [2] LEP Electroweak Working Group,  
<http://lepewwg.web.cern.ch/LEPEWWG/Welcome.html>.
- [3] J. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. A. Olive and M. Srednicki, Nucl. Phys. B238 (1984) 453; H. Goldberg, Phys. Rev. Lett. 50 (1983) 1419.
- [4] A. T. Lee *et. al.*, MAXIMA Collaboration, astro-ph/0104459; C. B. Netterfield *et. al.*, BOOMERANG Collaboration, astro-ph/0104460; N. W. Halverson *et. al.*, DASI Collaboration, astro-ph/0104489; P. de Bernardis *et. al.*, astro-ph/0105296.
- [5] M. W. Goodman and E. Witten, Phys. Rev. D31 (1985) 3059.
- [6] “Searches for the Neutral Higgs Bosons of the MSSM: Preliminary Combined Results Using LEP Data Collected at Energies up to 209 GeV”, The ALEPH, DELPHI, L3 and OPAL coll., and the LEP Higgs Working Group,  
<http://lephiggs.web.cern.ch/LEPHIGGS>.
- [7] M.S. Alam *et. al.*, [CLEO Collaboration], Phys. Rev. Lett. 74 (1995) 2885 as updated in S. Ahmed *et. al.*, CLEO CONF 99-10; BELLE Collaboration, BELLE-CONF-0003, contribution to the 30th International conference on High-Energy Physics, Osaka, 2000.
- [8] H. N. Brown *et. al.*, Muon  $g - 2$  Collaboration, Phys. Rev. Lett. 86 (2001) 2227.
- [9] J. L. Lopez, D. V. Nanopoulos and X. Weng, Phys. Rev. D49 (1994) 366.
- [10] A. B. Lahanas, D. V. Nanopoulos and V. C. Spanos, Mod. Phys. Lett. A16 (2001) 1229, hep-ph/0009065.
- [11] M. Drees, Y. G. Kim, T. Kobayashi and M. M. Nojiri, Phys. Rev. D63 (2001) 115009.

- [12] A. B. Lahanas, D. V. Nanopoulos and V. C. Spanos, Phys. Rev. D62 (2000) 023515.
- [13] J. Ellis, D. V. Nanopoulos and K. A. Olive, Phys. Lett. B508 (2001) 65, hep-ph/0102331.
- [14] L. Everett, G. L. Kane, S. Rigolin and L. Wang, Phys. Rev. Lett. 86 (2001) 3484; J. L. Feng and K. T. Matchev, Phys. Rev. Lett. 86 (2001) 3480; E. A. Baltz and P. Gondolo, Phys. Rev. Lett. 86 (2001) 5004; U. Chattopadhyay and P. Nath, hep-ph/0102157; S. Komine, T. Moroi and M. Yamaguchi, Phys. Lett. B506 (2001) 93; J. Hisano and K. Tobe, hep-ph/0102315; R. Arnowitt, B. Dutta, B. Hu and Y. Santoso, Phys. Lett. B505 (2001) 177; K. Choi, K. Hwang, S. K. Kang, K. Y. Lee and W. Y. Song, hep-ph/0103048; S. P. Martin and J. D. Wells, Phys. Rev. D64 (2001) 035003; S. Komine, T. Moroi and M. Yamaguchi, Phys. Lett. B507 (2001) 224; H. Baer, C. Balazs, J. Ferrandis and X. Tata, hep-ph/0103280; Y. G. Kim and M. M. Nojiri, hep-ph/0104258; V. Barger and C. Kao, hep-ph/0106189.
- [15] L. Roszkowski, R. R. Austri and T. Nihei, hep-ph/0106334.
- [16] A. B. Lahanas and V. C. Spanos, hep-ph/0106345.
- [17] M. Drees and M. M. Nojiri, Phys. Rev. D47, 376 (1993); H. Baer and M. Brhlik, Phys. Rev. D53 (1996) 597 and Phys. Rev. D57 (1998) 567; H. Baer, M. Brhlik, M. A. Diaz, J. Ferrandis, P. Mercadante, P. Quintana and X. Tata, Phys. Rev. D63 (2001) 015007; J. Ellis, T. Falk, G. Ganis, K. A. Olive and M. Srednicki, hep-ph/0102098.
- [18] J. A. Bagger, K. Matchev, D. M. Pierce and R. -J. Zhang, Nucl. Phys. B491 (1997) 3.
- [19] J. L. Feng, K. T. Matchev and F. Wilczek, Phys. Lett. B482 (2000) 388.
- [20] R. Abusaidi *et. al.*, CDMS Collaboration, Phys. Rev. Lett. 84 (2000) 5699.
- [21] R. Bernabei *et. al.*, DAMA Collaboration, Phys. Lett. B480 (2000) 23.

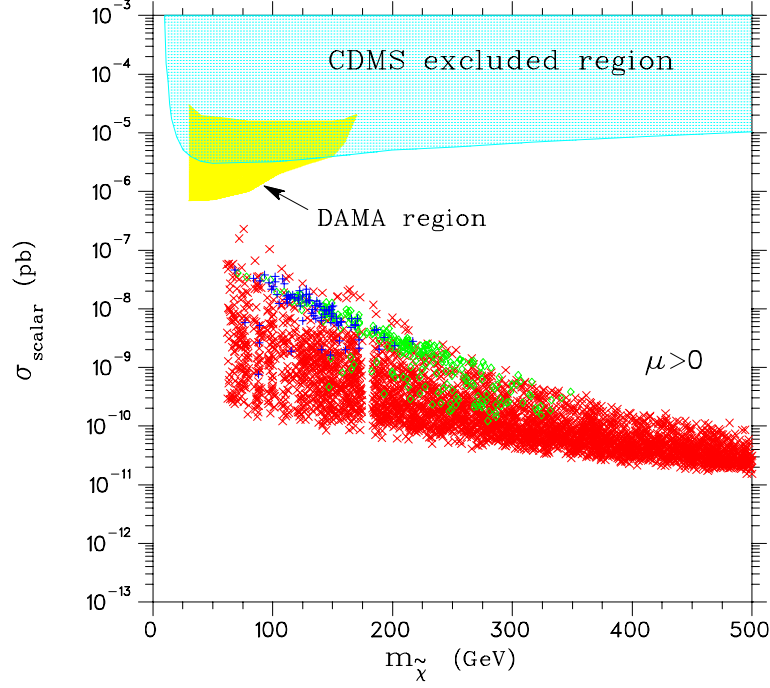


Figure 1: Scatter plot of the scalar neutralino-nucleon cross section versus  $m_{\tilde{\chi}}$ , from a random sample of 45,000 points. On the top of the figure the CDMS excluded region and the DAMA sensitivity region are illustrated. Pluses (+) are points within the E821 experimental region  $\alpha_{\mu}^{\text{SUSY}} = (43.0 \pm 16.0) \times 10^{-10}$  and also cosmologically acceptable  $\Omega_{\tilde{\chi}} h_0^2 = 0.13 \pm 0.05$ . Diamonds ( $\diamond$ ) are also cosmologically acceptable points, but with  $\alpha_{\mu}^{\text{SUSY}}$  within the region  $11 \times 10^{-10} < \alpha_{\mu}^{\text{SUSY}} < 75 \times 10^{-10}$ . Crosses ( $\times$ ) represent the rest of the random sample. The Higgs boson mass bound  $m_h > 113.5$  GeV is properly taking into account.

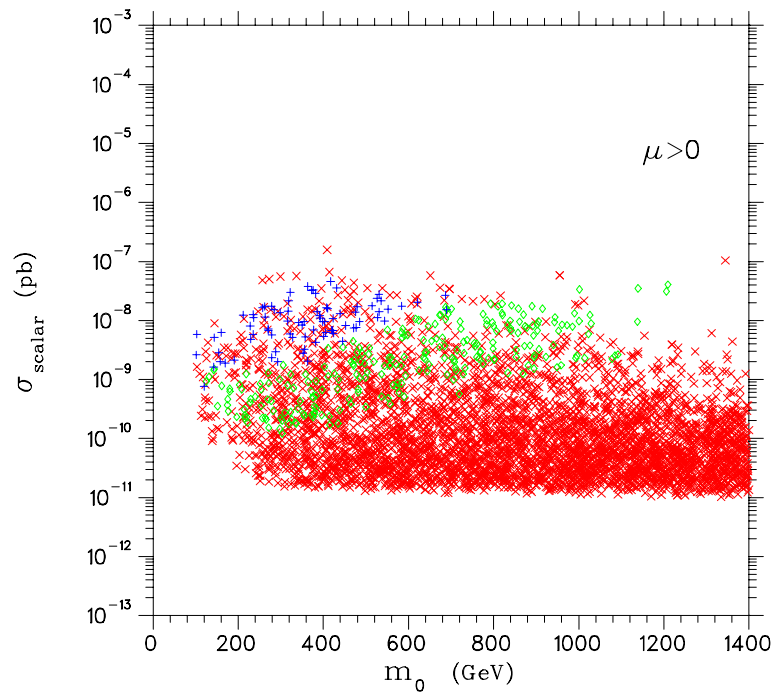


Figure 2: In this figure we display the scalar neutralino-nucleon cross section versus  $m_0$ . Points are as in Fig. 1.

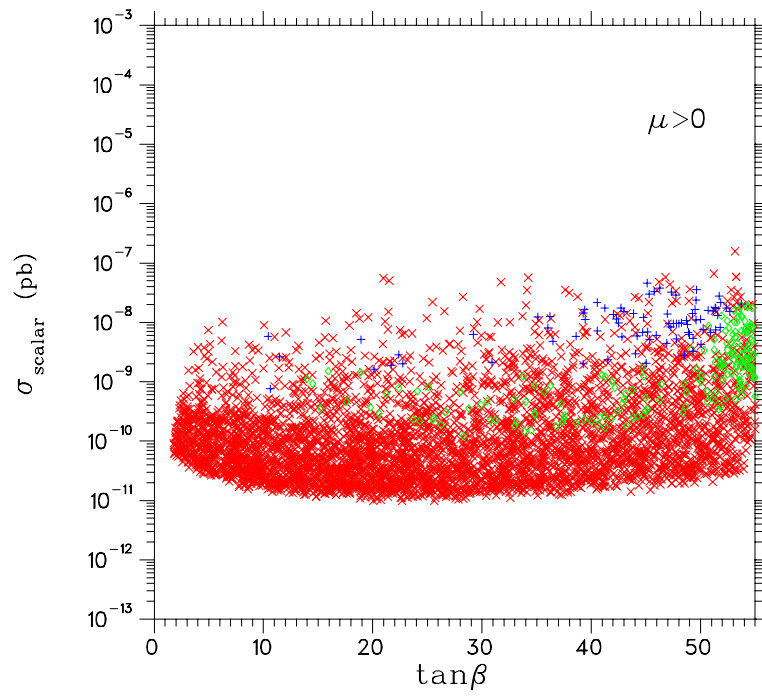


Figure 3: In this figure we display the scalar neutralino-nucleon cross section versus  $\tan\beta$ . Points are as in Fig. 1.

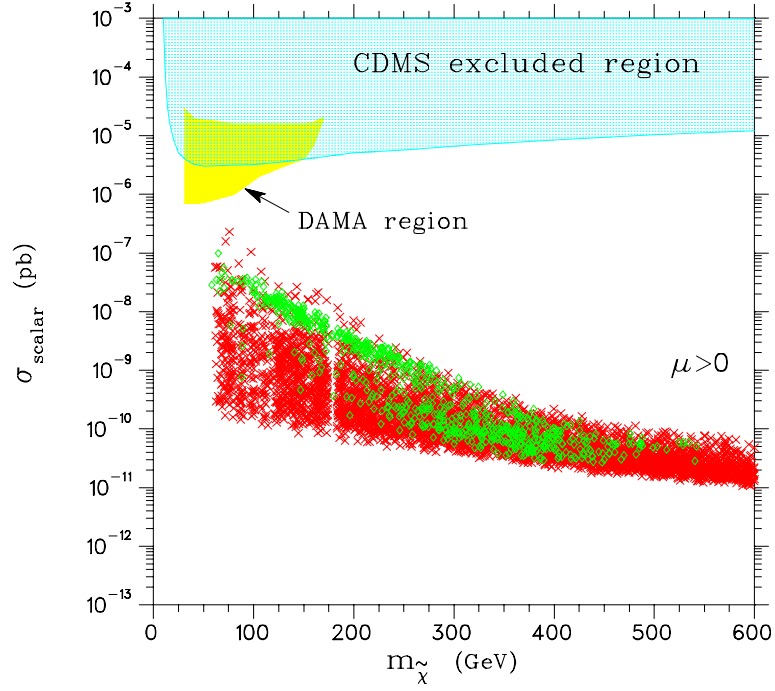


Figure 4: Scatter plot of the scalar neutralino-nucleon cross section versus  $m_{\tilde{\chi}}$ , from a random sample of Fig. 1. Diamonds ( $\diamond$ ) are cosmologically acceptable points, without putting an restriction from the  $\alpha_{\mu}^{\text{SUSY}}$ . Crosses ( $\times$ ) represent points with unacceptable  $\Omega_{\tilde{\chi}} h_0^2$ .

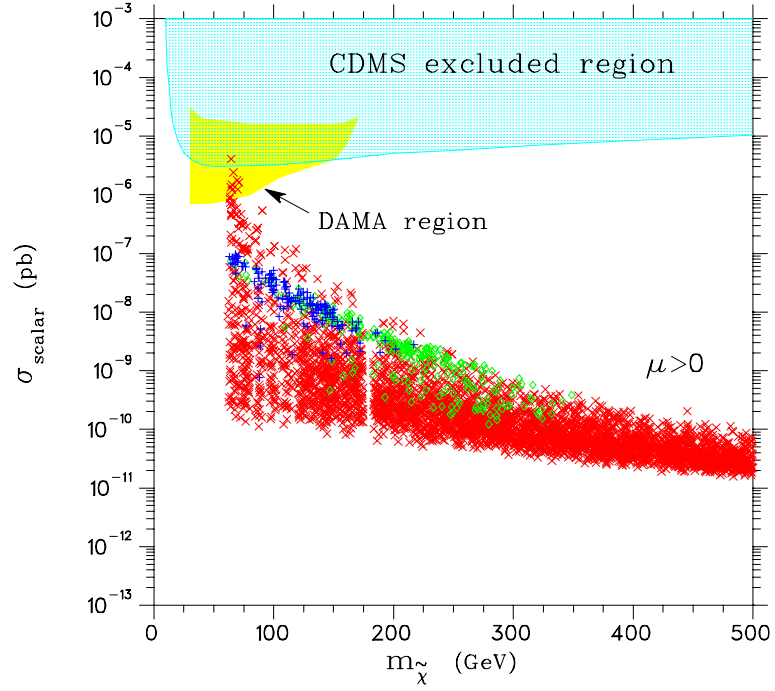


Figure 5: Scalar neutralino-nucleon cross section versus  $m_{\tilde{\chi}}$ . Points are as in Fig. 1. Here the Higgs boson mass bound ( $m_h > 113.5$  GeV) has been relaxed and the bound  $m_h > 100$  GeV is used.